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THE RELATION OF THE SOUNDS OF FOG SIGNALS TO OTHER SOUNDS.

BY CHARLES A. WHITE, SMITHSONIAN INSTITUTION, WASHINGTON, D. C.

IT is now generally known that within the range of possible audibility of most, if not all, the fog signals which the various civilized governments have established along their coasts, each usually in connection with a lighthouse, there are certain areas within which the sound of these signals are inaudible. It is also known that areas of more or less complete inaudibility of sounds, when projected from certain directions, sometimes occur upon the land; but only those which occur upon the water will be specially referred to in this article, and they will be discussed only with reference to their relation to stationary fog signals. Such acoustic conditions being a constant menace to navigation during a fog, the various governments concerned have instituted inquiry into the character and limitations of those areas and, incidentally, into their causes. Our own government has been, and still is, active in experimental studies of this kind, but the records do not show that any of those studies have been more than incidentally directed to that particular phase of the subject which is indicated by the title of this article.

The areas of inaudibility referred to are of two kinds, each area of both kinds bearing a similar special relation to a neighboring fog signal. One of these kinds is made such in every case by a true acoustic shadow of a stationary visible object, usually a small elevated island, or a ridge of land running out into the water, at, or near, one side of which the fog signal is located. That is, such an area is simply one which an essentially permanent acoustic shadow occupies.

The areas of inaudibility of the other kind occur in broad open waters. There is never any visible indication of their presence, and in connection with, or near, none of them is there any visible object above the water surface, and therefore nothing which could cast a true acoustic shadow there. Whatever may be the cause or causes of inaudibility of the sounds of the neighboring fog signal in areas of this kind, it is evident that at least a considerable part of the acoustic conditions prevailing in them are in effect identical with conditions which characterize the other kind. That is, certain of the effects produced within these areas are the same as those which are produced by a true acoustic shadow in each of the first mentioned kind of areas.

It is impracticable to discuss these areas and to compare each kind with the other without applying to each kind a distinctive name. I have therefore selected for the first mentioned kind the name montumbral, and for the second, the name pseudumbral, areas. The first name is selected because the areas to which it is applied are in every case made such by the acoustic shadow of a hill or ridge. The second name is selected because the acoustic conditions which prevail in the kind of areas to which it is applied are, as has just been mentioned, largely identical with those which are produced in the other kind by true acoustic shadows.

The elevated island or ridge which lies between a fog signal and a montumbral area casts an acoustic shadow over the latter just as at night it casts an optic shadow over the same area by intercepting the light from the lighthouse with which the fog signal is connected. The bounderies of a montumbral area are therefore determined by the profile outline of the elevated island or ridge which causes it, but they are modified and restricted, as compared with those of an optic shadow, by the great lateral diffusion of the sound waves, and by their tendency to soon coalesce beyond any object which may separate or obstruct them. That is, the lateral boundaries of an optic shadow diverge beyond the intercepting object, while those of an acoustic shadow have a strong tendency to converge there. The diagram which follows further on approximately illustrates the character of a montumbal area besides other conditions which sometimes may be connected with it, as will presently be explained.

It will thus been seen that what I designate as montumbral areas are in each case identical in outline with an acoustic shadow which is necessarily permanent, or only slightly varying as to its boundaries with changes of atmospheric conditions. Beyond this, montumbral areas, unlike pseudumbral areas, as will presently be shown, are not potentially variable. Acoustic shadows occur under a great variety of conditions, but montumbral areas as I have defined them are not numerous.

Excepting the absence of the direct sounds of the fog signal within a montumbral area the acoustic conditions prevailing there are normally the same as are those which prevail on all the water surface adjacent to it. That is, in case no other acoustic shadows are cast there by other objects, intercepting other neighboring sounds, it is an area of inaudibility only of the sounds of the neighboring fog signal and of such other sounds as may be projected from points within a limited distance upon either side of the fog signal. This inaudibility is caused by a complete interception or destructive arrest, by the adjacent elevated island or ridge, of a portion of the sounds which the fog signal projects towards it. All other sounds of whatsoever kind, if sufficiently intense for such distances, may, with the following exceptions, be projected from, into, or across the area in any direction.

The exceptions are that, because the elevated island or ridge intervenes, sounds connot be projected to points adjacent to its other side from points within the montumbral area, and of course such sounds cannot reach the place of origin of the neighboring fog signal's sounds. Also, the projection of other sounds than those of the neighboring fog signal into the montumbral area from points at such distances at either side of the fog signal as accord with the length of the elevated island or ridge, will be more or less completely prevented by the presence of the latter, just as it prevents the projection of the fog signal's sounds into that area.

Pseudumbral areas are of more frequent occurrence than are montumbral areas, and in various ways they are more important. Still, their discovery is always empirical because there is never any visible indication of their ex-

istence ; and when one is discovered its shape and extent can be known only by special investigation. It is known, however, that the shape and extent of pseudumbral areas are very variable, and also that their location is uncertain as regards distance and direction from the fog signals whose sounds are inaudible within them. They are also very variable in outline, and the distinctness of the boundary of each is usually, if not always, variable in its different parts. That is, if the area may be propery designated as umbral, the term penumbral may not inappropriately be used to indicate the indefiniteness of certain portions of the boundaries of those areas.

Furthermore, certain known facts indicate that all the conditions which characterize a pseudumbral area at one time may be absent from nearly or quite the whole area at another time. These areas, therefore, unlike montumbral areas, are always potentially, and apparently always actually, variable, not only in outline but in position and duration. Still, they frequently have sufficient permanence for systematic study; and Major W. R. Livermore, Engineer in Charge of the First and Second United States Light House Districts, has successfully mapped some of them.

Experimental study of pseudumbral areas is necessarily made on board of vessels, and as the observer directs his course away from the fog signal, which is meanwhile kept regularly sounding, he becomes aware of having reached the proximal boundary of a pseudumbral area by the gradual, or often sudden, failure of the fog signal's sounds to reach him. Continuing in that direction, if open water be there, he comes to the distal boundary of the area when the fog signal's sounds are again heard, usually with little diminution of their intensity. The biological terms, proximal and distal, are borrowed and applied to the nearer and opposite sides, respectively, of the area, with reference to the location of the fog signal.

Although, as has already been mentioned, a considerable part of the acoustic conditions which prevail in a pseudumbral area are, in effect, identical with conditions which characterize montumbral areas, two important differences between the conditions prevailing in the two areas respectively are known, besides the difference as to permanency just mentioned. First, in the case of a pseudumbral area there is no such interception or destructive arrest of any portion of the fog signal's sounds by a visible physical object as takes place in the case of a montumbral area. The inaudibility is caused by some invisible physical force or condition, but how that force acts, or what that condition really is, has long been the subject of wide differences of opinion and of earnest controversy. Second, independent sounds *can* be projected from points within a pseudumbral area to the place of origin of the neighboring fog signal's sounds, further mention of which fact will presently be made.

The cases discussed under the head of Acoustic Reversibility by Professor Tyndall,[1] and some of those related by Professor Henry[2] concerning his experiments while he was Chairman of the United States Light House Board, agree with the foregoing statements, one of the latter cases being especially important in this connection.

Many of Professor Henry's experiments were made to ascertain the relation to one another of sounds responsively produced, such, for example, as those which he made with the whistles of steamers off Sandy Hook in 1874. He showed that sounds may be returned from an area in which similar reciprocal sounds, projected from other points, are inaudible, and he urged this fact against Professor Tyndall's theory that the cause of such inaudibility is a flocculent condition of the atmosphere. The experiment which I wish particularly to refer to, however, was made with reference to the sounds of a stationary fog signal, and it is therefore of special interest to the subject of this article. The result of this experiment was the projection from within a pseudumbral area of the sounds of the whistle of the steamer upon which he was making his observations to the immediate vicinity of the neighboring fog signal. While the steamer was moving away from the fog signal, which was meanwhile kept regularly sounding, the steamer entered an area where the sounds of the fog signal became inaudible. The steamer's whistle being then blown, its sounds were distinctly heard by observers standing beside the fog signal.

Professor Henry died soon after the last of the experiments referred to were made, and they have not, to my knowledge, been continued. However, considering the facts which he then demonstrated, together with other facts concerning the acoustic conditions which are known to prevail in both pseudumbral and montumbral areas, I cannot doubt that sounds of any kind, if sufficiently intense for such distances, may be projected into or across pseudumbral areas as readily, and in the same manner, as into or across montumbral areas. That is, I think the facts now known warrant the opinion that a pseudumbral area is one of inaudibility only of sounds coming toward that side of it which faces the neighboring fog signal.

The question may be raised whether the acoustic conditions which usually prevail in connection with pseudumbral areas may not sometimes be complicated by the simultaneous presence of such an additional force or condition as would make them areas of inaudibility of certain other sounds besides those of their neighboring fog signals. I am not aware of any fact which favors the supposition that such complications ever exist, nor do I now think they are to be expected. This statement, however, has no reference to the assumed inaudibility within the pseudumbral area of sounds which may be projected from points within a short distance upon either side of the fog signal, because it is evident that, to a greater or less extent, such sounds are controlled by the same cause which controls the fog signal's sounds. The question may also be raised whether the condition which produces inaudibility of the fog signal's sounds, without reference to other sounds, may not also be complex. I am not, however, at present prepared to discuss the question of causes of inaudibility of sounds in pseudumbral areas. Still, I think that exhaustive investigations concerning the relation of the sounds of fog signals to other sounds, in connection with pseudumbral areas, are likely to throw much light upon it.

In view of the variability of those areas it is evidently desirable that various experiments showing such relation should be simultaneously made when one of them is discovered. For example, it is desirable that several vessels, each provided with the means of producing various penetrating sounds, should surround and traverse the pseudumbral area and attempt the projection of those sounds into, from, and across it in all directions; the neighboring fog signal being meanwhile kept regularly sounding. As a matter of course all such experiments should be accompanied by observations of all atmospheric conditions, especially those which affect, or which are supposed to affect, the propagation of sounds.

Such experiments would tend to show, among other things, what becomes of the sounds of a fog signal upon reaching the proximal boundary of a pseudumbral area. For example, if it should be ascertained that such sounds as I have indicated may be projected in various directions through the very space in which a fog signal's sounds are at the same time inaudible, it would demonstrate what I

[1] Tyndall, John ; Sound, 3rd edition, p. 403.
[2] Henry, Joseph ; Researches in Sound, pp. 493, 501, 503, 510 and 547.

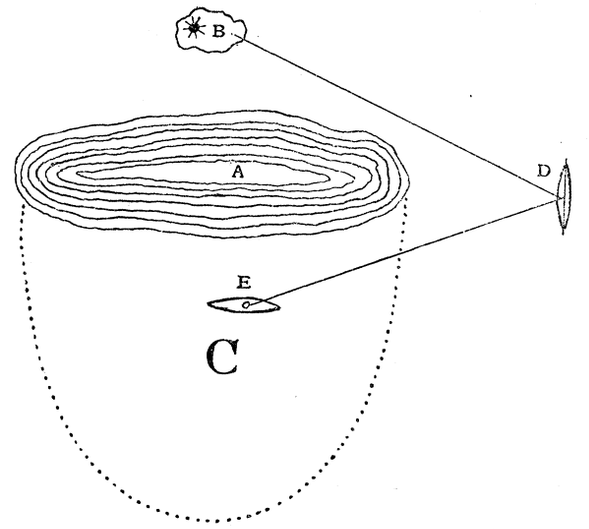
have suggested, that such inaudibility is mainly, if not wholly, dependent upon causes acting in only one direction. If then it should be ascertained that independent sounds may be projected from a point just within the proximal boundary of a pseudumbral area to a point beyond its distal boundary, it would of itself be a demonstration that the fog signal's sounds become either refracted or annulled at the proximal boundary of the area.

The frequent, if not the usual, recovery of the fog signal's sounds in strong intensity beyond the distal boundary of a pseudumbral area seems to show that there has been no permanent annulment of those sounds either at the proximal boundary or elsewhere. It also seems to indicate that their restoration is at most only in part due to such diffusion and coalescence of sound waves of the fog signal as quickly restricts the extent of a montumbral area, and makes those sounds audible beyond its distal boundary. It therefore becomes desirable to investigate the air above pseudumbral areas with a view to learning whether the fog signal's sounds pass there uninterruptedly to the distal side of the area. The investigations by balloon which have been proposed by both Mr. Johnson and Major Livermore will evidently be the means of testing this question, and they will doubtless aid in other ways to increase our knowledge of the acoustic conditions which prevail in pseudumbral areas.[3]

The preceding paragraphs are largely suggestive of scientific results yet to be attained. The facts now to be mentioned are suggestive of dangers to navigation to be avoided or guarded against. Last autumn, while a member of the party of investigation whose operations were described by Mr. A. B. Johnson in *Science* for January 5th of the present year, I made some observations of echoes of the sounds of fog signals which are of special interest in this connection. The most important of these observations were made upon Great Gull Island, at the eastern end of Long Island Sound, and the echoes were those of the fog signal, a siren, which is connected with the lighthouse on Little Gull Island, about half a mile from my point of observation. There was no fog at the time these observations were made, but the siren's sounds were given regularly that their variations of audibility might be studied in the surrounding region.

The echoes were received from the sails of several schooners which were standing in the offing with all sails set and close hauled by the wind. The vessels varied in distance from me and from the siren from half a mile to nearly two miles. The wind was light, there was perfect silence around me, and the echoes reached me with almost startling distinctness. In timbre, or quality, they were exact reproductions of the siren's sounds; and in duration and time-interval they also agreed with them. I estimated the intensity of the echoes at from 1 to 3 in a scale of 10, the latter number representing the full intensity of the siren's sounds. The angles of incidence and reflection by which they reached me were from 20, to somewhat more than 40 degrees.

Considering the intensity and distinctness of those echoes, their identity of timbre, time-length and time interval with those of the direct sounds of the siren, the distances from which they were reflected, and the broad angles of incidence and reflection by which they reached me, I was impressed with the belief that such echoes, when heard within either pseudumbral or montumbral areas, may be a source of danger to passing vessels. The following diagram will show how sail-echoes of a fog signal may be a source of danger to a vessel traversing a montumbral area in a fog, and it also illustrates the character of montumbral areas as they have already been described.



A, represents an elevated island; *B*, a small island with lighthouse and fog signal, and *C*, a montumbral area, the seat of an acoustic shadow caused by the elevated island. *D*, represents a schooner with all sails set and close hauled. *E*, represents another vessel, within the montumbral area, where of course the direct sounds of the fog signal are inaudible. Those sounds, however, reach the sails of the vessel at *D*, and are reflected to the vessel at *E*, as an echo. To persons on board the vessel at *E*, the sounds of the fog signal seem to come from the direction of *D*.

Sail-echoes of a fog signal which are recovered beyond the distal boundary of a montumbral area may, perhaps, also be reflected back into it, but lateral reflections, such as are represented by the diagram, are probably more likely to occur.

It cannot be denied that the permanent conditions necessary for the casting of an acoustic shadow of a fog signal's sounds across a navigable channel, or a usual track of vessels, are not common, but such conditions do exist in connection with certain of the fog signals which have been established along our coasts. Neither can it be denied that the occurrence of such a combination of permanent and adventitious conditions for reflecting the sounds of a fog signal from the sails of vessels into a montumbral area as is represented by the foregoing diagram is likely to be rare. Still, there is an undeniable probability that such cases may occur at any time, and it is also undeniable that they may be attended with danger whenever they do occur.

If my assumption is correct that a pseudumbral area is one of inaudibility of only such sounds as are projected towards that side of it which faces the neighboring fog signal it may legitimately be assumed that sail-echoes of the fog signal's sounds may be projected into such an area just as they may be projected into a montumbral area. That is, if a pseudumbral area should be a short one, sail-echoes of the neighboring fog signal may be projected into it laterally in the same manner that they are represented by the foregoing diagram as being projected into a montumbral area. Recovered sounds of the fog signal, upon the distal side of the pseudumbral area, may also be echoed back into that area from the sails of vessels. Such echoes may enter a pseudumbral area from any point of the compass within a range of, perhaps, one half the horizon. To persons on board a vessel traversing one of these areas during a fog those echoes might readily be mistaken for the direct sounds of the fog signal, and the true location of the latter would in every case be falsely indicated.

The conditions under which echoes occur are numberless, and their observation has from time immemorial been prominent among the practical duties of mariners. They habitually use echoes of permanent objects as aids,

[3] Since the foregoing paragraphs were written Major Livermore has informed me that in experiments lately performed under his direction the sounds of a bell and of a steamer's whistle were projected both into and out of pseudumbral areas, thus demonstrating in large part what I have suggested.

and as warnings from danger, when guiding their vessels in a fog or in darkness; and sail-echoes of sounds from their own vessels are always to them warnings of possible danger of collision. The cases which I have mentioned, however, are all of a special and accidental character. That is, they are special because they are connected only with fog signals, and accidental because they depend upon the fortuitous movements of sail vessels.

Cases of the projection of sail-echoes of the sounds of fog signals into pseudumbral areas, like those suggested for montumbral areas, will probably not be numerous, but both kinds of cases are worthy of careful investigation, not only because of the inherent importance of the subject to which they relate, but because they are incidental sources of danger which have been introduced by the establishment of fog signals.

THE ENEMIES OF LEPIDOPTEROUS PUPÆ ENCLOSED IN BARK-FORMED COCOONS.

BY EDWARD B. POULTON, M.A., F.R.S., HOPE PROFESSOR OF ZOÖLOGY IN THE UNIVERSITY OF OXFORD, ENGLAND.

THE beautiful and perfect concealment of the cocoons constructed out of bark by many species of Lepidoptera has often attracted attention and admiration. In some species, such as the British *Acronycta leporina*, the larva tunnels deeply into the bark, constructing a chamber at some distance beneath the surface, and carefully removing the bark-dust formed by its building operations. The mouth of the tunnel is closed by fragments of bark spun together so as to form a covering exactly flush with the surrounding surface, which it also resembles in texture and color. In other species a natural crack or furrow in the bark is selected by the larva and is similarly covered in level with the bark around. In the genus *Cerura* (*Dicranura*) the larvæ excavate an oval area which is covered in by a more or less domed roof, similarly built of pieces of bark so well fitted and woven together that the appearance is exactly that of some rounded, flattened or irregular projection on the trunk of the tree. Furthermore, in the choice of situation it is usually found that increased aid to concealment is afforded; the apparent projection being formed on an appropriate part of the trunk, and with due regard to the existence, arrangement and direction of the irregularities of its surface, such as furrows, etc. Those who believe in the efficiency of Natural Selection in evolution will probably regard this interesting method of concealment as the outcome of countless generations during which the attacks of enemies have been, on the whole, more successful against the products of less perfected instincts, and less so against those of the more perfected. Furthermore, we must suppose that the increasing perfection in instincts has acted selectively on enemies, sharpening their faculties, until, by action and reaction, the present high level of constructive skill has been reached, and is maintained.

How far is it possible to gain evidence of such a relationship between enemies and prey? At first sight, one of the cocoons I have described appears to be so perfectly concealed as to defy the sharpness of any enemy, however acute. But observation, especially directed to this end, will show that such an inference is incorrect.

On April 12 of the present year I was examining the bark of a black poplar (*Populus nigra*) near Yoxford, in Suffolk, and found a cocoon of the "Poplar Kitten" (*Cerura bifida*) which had evidently been recently opened by some enemy, almost certainly a bird, and the chrysalis extracted. The edges of the opening were still brown and fresh, as was the interior of the cocoon; and the larval skin remained fresh and untouched inside. The opening was in the middle of the exposed surface and not at one end, as it is when the moth emerges. Besides, the cocoon had been opened and cracked by a blow from some hard object such as a bird's beak, and the sharp irregular margins were quite different from those of the natural opening made by the moth, doubtless by means of a corrosive fluid, as in the allied species, *Cerura Vinula*, which Mr. I. H. Latter has recently shown to secrete caustic potash for this purpose. Furthermore, the moth emerges far later in the year, and, had it emerged at an exceptional time, the empty pupal skin would have been left behind in the cocoon. We may therefore safely assume that the opening was the work of an enemy, and, as the cocoon was five feet from the ground, it was probably due to some tree-creeping, bark-exploring species of bird.

After the hint supplied by this observation I found that such instances are quite common and that a considerable proportion of these cocoons are thus opened and their contents abstracted. It is probable that the attention of the enemy is directed to any cocoon-like object by the sense of sight and that the object is then tapped, and, if found to be hollow, opened and the pupa devoured. If I am right in supposing that the pupa has to run the gauntlet of such dangers as these, it follows that any carelessness in construction or in the selection of a site would tend to be eliminated, and we are able to picture to ourselves, with a considerable degree of probability, the kind of conditions under which this wonderful form of protective concealment has been developed and is now maintained.

These conclusions are perhaps capable of being brought to a crucial test, and, as this involves much time and much observation, it is to be hoped that several naturalists may attack the question. During the winter and spring a large number of such examples should be collected and noted, with special reference to the degree of concealment exibited by the opened cocoons as compared with those which are found to have escaped attack. The subjective element would require to be checked by calling in the aid of others who are ignorant of the point under consideration but possess the requisite accuracy of eye. Attention should only be paid to fresh cocoons which have been opened in the season of the observation; for the old battered cocoons of past seasons will be commonly found on the trunks. It may be that the problem demands too large a number of examples to be capable of solution in this way; but on the other hand it is possible that positive evidence may be forthcoming.

AN OBSERVATION ON THE TERMINAL VERB IN INFANT SPEECH.

BY E. W. SCRIPTURE, NEW HAVEN, CONN.

IT has sometimes been asserted that the most natural position for the verb is not at the end of the sentence, and that children would not of themselves separate the participle or infinitive from the auxiliary or main verb, as is done in German syntax. I wish to record a personal observation to the contrary.

The child, W.S., twenty-nine months old, has not learned any language but English, and has not heard any sentences constructed otherwise than according to correct grammatical rules. W. S. was told to ask for some money to buy shoes, but in doing so said, "I want some money for my shoes to buy." Upon the question "What?" the sentence was repeated without change. On other occasions W. S. uses the words in the customary order, *e. g.*, "I'm going buy new shoes." The observation seems to prove that the terminal position of the infinitive is at least not unnatural